Pergamon

J. stored Prod. Res. Vol. 34, No. 4, pp. 251–262, 1998
Published by Elsevier Science Ltd
Printed in Great Britain
0022-474X/98 $19.00 + 0.00

PII: S0022-474X(98)00006-X

Predicting Insect Density from Probe Trap Catch in Farm-stored Wheat

DAVID W. HAGSTRUM[1]*, PAUL W. FLINN[1] and Bh. SUBRAMANYAM[2]

[1]*Grain Marketing and Production Research Center, Agricultural Research Service, United States Department of Agriculture, 1515 College Ave., Manhattan, KS 66502, USA and* [2]*Department of Entomology, University of Minnesota, St. Paul, MN 55108, USA*

(Accepted 29 January 1998)

Abstract—Insect populations infesting wheat stored in four bins on two Kansas farms were monitored from early July 1996 through to the middle of January 1997. Estimates of adult insect density based upon the numbers of adult insects caught using probe traps differed from those based upon the number of insects found in grain samples. These differences were a result of differences in numbers of insects found and percentages of traps or grain samples with insects. Traps detected insects 15 to 37 d earlier than grain samples. The depth of traps below the grain surface tended to influence both the total number and species composition of the insects that were caught. Traps inserted with the top just below the grain surface collected an average of 1.9 times more *Cryptolestes ferrugineus* (Stephens), 1.2 times more *Rhyzopertha dominica* (F.), 4.1 times more *Ahasverus advena* (Waltl) and 77.4 times more *Typhaea stercorea* (L.) than traps inserted with the top 7.6 cm below the grain surface. However, trap depth did not have a significant effect on the number of *R. dominica* caught and on only 12 to 21% of sampling dates did trap depth have a significant effect on the number of insects of other species that were caught. Grain temperatures in three of the bins averaged 30°C during the first 70 d of storage and then decreased by 0.2°C/d. Grain in the other bin was initially more than 10°C warmer and grain temperature decreased by 0.2°C/d over the full storage period. The numbers of insects captured in traps decreased as grain temperature decreased even though grain samples indicated that insect populations were still growing. Thus, trap catches did not estimate insect population density consistently throughout the storage period. A method was developed in the current paper to adjust for the effect of seasonal changes in temperature on trap catch. Published by Elsevier Science Ltd

Key words—detection, monitoring, sampling, trapping, insects, stored wheat

INTRODUCTION

Insect populations in stored grain are generally monitored by taking grain samples or by using traps. Grain samples are taken with a grain trier, deep bin cup or vacuum probe (Hagstrum *et al.*, 1995). Probe traps are cylindrical tubes with perforations in the upper section through which insects drop into the trap. These traps have a pointed tip for easy insertion into the grain. A brass probe trap developed by Loschiavo and Atkinson (1967) for detecting insects in stored grain has been redesigned several times using newer and less expensive plastic materials

This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation by USDA or University of Minnesota for its use.

*Author for correspondence.

(Loschiavo and Atkinson, 1973; Burkholder, 1984; Barak *et al.*, 1990; Madrid *et al.*, 1990; White *et al.*, 1990). White and Loschiavo (1986) developed a stacked version of the probe trap for investigating insect activity at different grain depths. Shuman *et al.* (1996) developed instrumentation for estimating probe trap catches electronically.

Probe traps detect insects when no insects are detected by standard grain sampling methods (Barak and Harein, 1982; Wright and Mills, 1984; Lippert and Hagstrum, 1987; Hillmann, 1991; Reed *et al.*, 1991; Gates, 1995; Pereira *et al.*, 1994; Vela-Coiffier *et al.*, 1997). Probe traps have been used in surveys to detect insect infestations (Loschiavo, 1975; Weinzierl and Porter, 1988; Subramanyam and Harein, 1989; Madrid *et al.*, 1990), in ecological studies to estimate adult insect population densities (Loschiavo, 1985; Loschiavo and Smith, 1986; Subramanyam and Harein, 1989; Reed *et al.*, 1991; Gates, 1995; Pereira *et al.*, 1994; Dowdy and McGaughey, 1994; Parajulee and Phillips, 1995; Vela-Coiffier *et al.*, 1997) and in insect control studies to evaluate the effectiveness of pest management methods (Arthur *et al.*, 1990; Arthur, 1994, 1995; Subramanyam *et al.*, 1994). For studies on insect ecology and evaluation of the effectiveness of pest management, estimation of insect densities generally is more important than detection.

Interpretation of trap catch is difficult because many factors influence trap catch. Trap catch increases proportionally with an increase in trapping duration (Fargo *et al.*, 1989; Cuperus *et al.*, 1990). Capture rate is influenced by insect species and grain temperature (Fargo *et al.*, 1989) and the type of grain (Wright and Mills, 1984). The number of insects caught in traps with one row of holes above the grain surface was generally similar to the number caught when the top of the trap was just below the grain surface (Subramanyam *et al.*, 1989). However, they found that 4.6-fold more adult hairy fungus beetles, *Typhaea stercorea* (L.), were caught in partially inserted traps. In wheat (Fargo *et al.*, 1994) and maize (Subramanyam *et al.*, 1993), catches were not significantly different between two commercial probe traps. Food baits or pheromone lures did not appear to substantially increase trap catch (Loschiavo, 1974; Loschiavo *et al.*, 1986; White and Loschiavo, 1986; White and Loschiavo, 1988; Hillmann, 1991; Fargo *et al.*, 1994; Plarre, 1996).

The present study examines the relationships among insect density in grain samples, grain temperature and probe trap catch during a 190-d storage period. The primary objective was to develop better methods of interpreting probe trap catch data for research and pest management programs. The depth of insertion of a probe trap below the grain surface and grain temperature were investigated as factors that might need to be considered in interpreting trap catch.

MATERIALS AND METHODS

Adult insect populations infesting hard red winter wheat stored in two bins of 109-ton capacity on one farm (bins A and B), and 87-ton (bin C) and 98-ton (bin D) on a second farm were monitored at 3- to 4-d intervals 51 times between 9 July 1996 and 15 January 1997. Both farms were near Enterprise, Kansas.

Two pairs of 45 cm long probe traps (Storgard WB Probe II, Trece, Salinas, CA) were placed in each bin one-third of the distance between the center and the bin wall. Traps were located away from the bin door towards the east and south sides of bins A and B, and the north and west sides of bins C and D. Within each pair, one trap was inserted with the top just below the grain surface and the other with the top 7.6 cm below the grain surface. The distance between the two traps within each pair was 60 cm. Traps were checked every 3 to 4 d.

Five grain samples of approximately 0.2 kg each were taken by inserting a 1.27 m open-ended grain trier (Model 39-A-OH, Seedburo Equipment, Chicago, IL) to a depth of 50 cm at or near each trap location before the traps were inserted into the grain. Another five grain samples were taken at or near these locations after removing the traps. One of the grain samples in each of these groups of five grain samples was taken at the location where a trap was to be inserted or had been inserted, and the other four from locations horizontally 7.6 cm away from this location in each of the four cardinal directions. Grain temperatures were measured 25 cm below the grain surface at trap locations using a Digi-Sense thermistor reader (Model 8523, Cole-Palmer

Instrument Co., Chicago, IL) with YSI series 400 thermistor probes (Yellow Springs Instrument, Yellow Springs, OH).

Adult insects were separated from the grain samples with an oblong-hole grain sieve (0.18 by 1.27 cm, Seedburo Equipment, Chicago, IL) and counted. Each grain sample was weighed (Model GT2100, Ohaus, Florham Park, NJ) and insect density was expressed as the number of adult insects/0.5 kg grain sample. Average adult insect densities in grain samples were based upon 10 grain samples taken at or near each trap location, 5 taken before inserting the trap and 5 taken after removing the trap. Grain moisture content of each sample was determined in the laboratory with a moisture meter (Model GAC II, Dickey-John Corp., Auburn, IL).

Linear regression was used to predict the rates of change in grain temperature during the storage period, and the numbers of insects per 0.5 kg grain sample from probe trap catch (SAS Institute, 1990). Separate regression equations predicting insect density from trap catch were fitted to data for <90, 90–135 and >135 d of storage to show the change in capture rate during the storage period. The same software also was used to plot data, do two-way analysis of variance and t-tests comparing the capture rates for traps at different depths below the grain surface, and do t-tests comparing the slopes of regression equations.

RESULTS

Seasonal changes in grain temperature

Wheat was harvested and stored in bins A, B and C at an average temperature of 30°C (Fig. 1). In bin D, the wheat was initially more than 10°C warmer than the wheat in the other bins. The regression equation describing grain temperature (T) as a function of storage time (st) during the first 70 d for bins A, B and C was $T = 30.1 - 0.025\ st$. The slope of 0.025°C/d was not significantly different from zero ($t = 1.70$; df = 48; $P > 0.10$). During the remainder of the storage period for bins A, B and C, and the full storage period for bin D the temperature–storage time relationship was described by the equation, $T = 40.7 - 0.20\ st$, with an r^2 of 0.93. The grain temperature decrease of 0.20°C/d was significantly different from zero ($t = 43.90$;

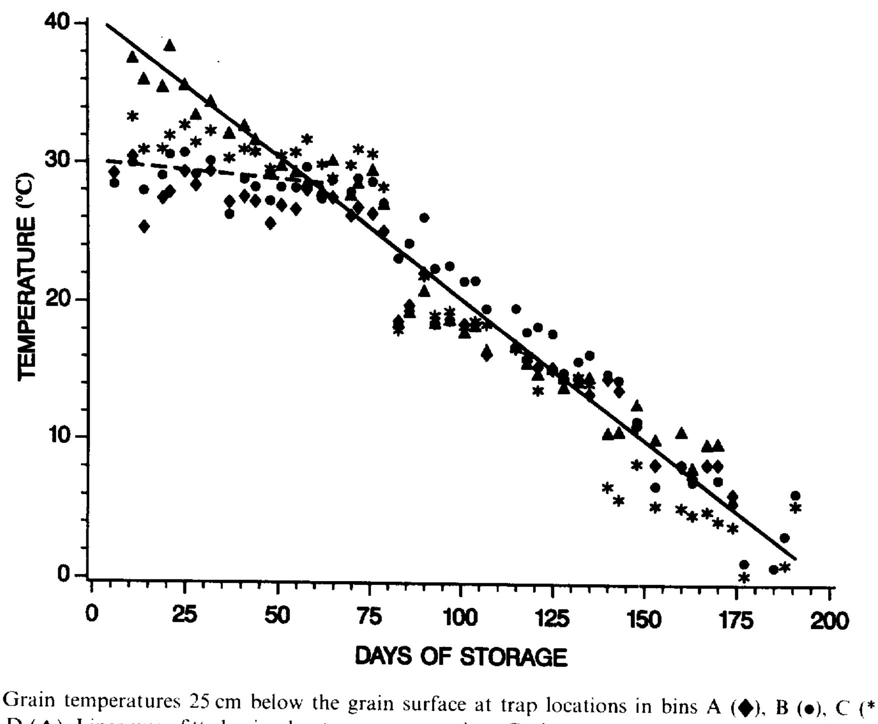

Fig. 1. Grain temperatures 25 cm below the grain surface at trap locations in bins A (♦), B (•), C (*) and D (▲). Lines were fitted using least square regression. Grain was stored in bins on 9 July 1996.

df = 134; $P < 0.001$). Average grain moisture contents during the storage period were 12.6, 11.3, 11.3 and 11.8% (wet-weight basis) in bins A, B, C and D, respectively.

Seasonal trends for insects

In all bins, estimates of insect density based upon the numbers of adult insects caught using probe traps differed from those based upon the number of insects found in grain samples (Fig. 2). The numbers of insects in grain samples indicated that rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), and lesser grain borer, *Rhyzopertha dominica* (F.), populations grew during much of the storage period. Early in the storage season, more *C. ferrugineus* were captured in probe traps than in grain samples. The difference between the number of insects in traps and the number in grain samples was smaller for *R. dominica*. Later in the storage period, probe trap catches for both species decreased as grain temperature decreased. A second peak in the *C. ferrugineus* population in bin B at day 120 (Fig. 2), which was nearly as large as the earlier peak, represented a decrease in capture rate. If the capture rate had not decreased, the second peak would have been much larger than the first, because insect populations were growing. More foreign grain beetles, *Ahasverus advena* (Waltl), and *T. stercorea*, also were captured in probe traps than in grain samples (Fig. 3).

Trap depth

The depth of trap below the grain surface tended to influence both the numbers and species composition of adult insects that were caught. Traps inserted with the top just below the grain surface collected an average of 1.9 times more *C. ferrugineus*, 1.2 times more *R. dominica*, 4.1 times more *A. advena* and 77.4 times more *T. stercorea* than traps inserted with the top 7.6 cm below the grain surface (Table 1). However, the effect of trap depth on catch was generally small (except for *T. stercorea*), inconsistent and not statistically significant. Traps inserted with the top 7.6 cm below the surface of grain did on some sampling dates catch more insects than traps with the top just below the surface. For *C. ferrugineus* (27% of dates) and *R. dominica* (43% of dates), this occurred more frequently than with *A. advena* (7% of dates) and *T. stercorea* (1% of dates).

Because insect density varied with sampling date, species and bin, a two-way analysis of variance was used to evaluate the effect of trap depth on catch over sampling dates and the statistical analysis was done by species and bin. For *R. dominica*, neither the effect of trap depth ($F < 1.05$; df = 1, 102; $P > 0.31$) nor the interaction of trap depth and sampling date ($F < 1.04$; df = 50, 102; $P > 0.42$) was significant in any of the bins. However, for the other species, the interaction of trap depth and sampling date was significant ($F > 1.96$; df = 50, 102; $P < 0.002$) for 10 out of 12 of the analyses of variances indicating that the significance of trap depth had to be tested separately for each sampling date. Over all four bins, catches were significantly different ($t > 6$; df = 2; $P < 0.01$) between trap depths on only 12, 19 and 21% of the sampling dates for *C. ferrugineus*, *A. advena* and *T. stercorea*, respectively. For 5 of 58 of these comparisons, traps inserted with the top 7.6 cm below the surface of grain caught significantly more insects than traps with the top just below the surface.

Earlier detection with traps than grain samples

Traps detected *C. ferrugineus* and *A. advena* 37 d before they were detected in grain samples. The time interval between detection with probe traps and detection with grain samples was 15 to 30 d for *R. dominica* and *T. stercorea*. For all species, the percentages of traps or grain samples with insects (Fig. 4) began to increase earlier and more rapidly than the numbers of insects per trap or grain sample (Figs 2 and 3). For all four species, the percentage of traps detecting insects was generally greater than the percentage of grain samples detecting insects throughout most of the storage period (Fig. 4).

Prediction of insect density from trap catch

The linear equation, $D = \beta_0 + \beta_1 C$, was used to describe the relationship between adult insect density (D) and trap catch (C) (Table 2). Except for *T. stercorea* ($r = 0.170$; df = 383; $P > 0.10$), the number of insects in grain samples was correlated with the number in probe

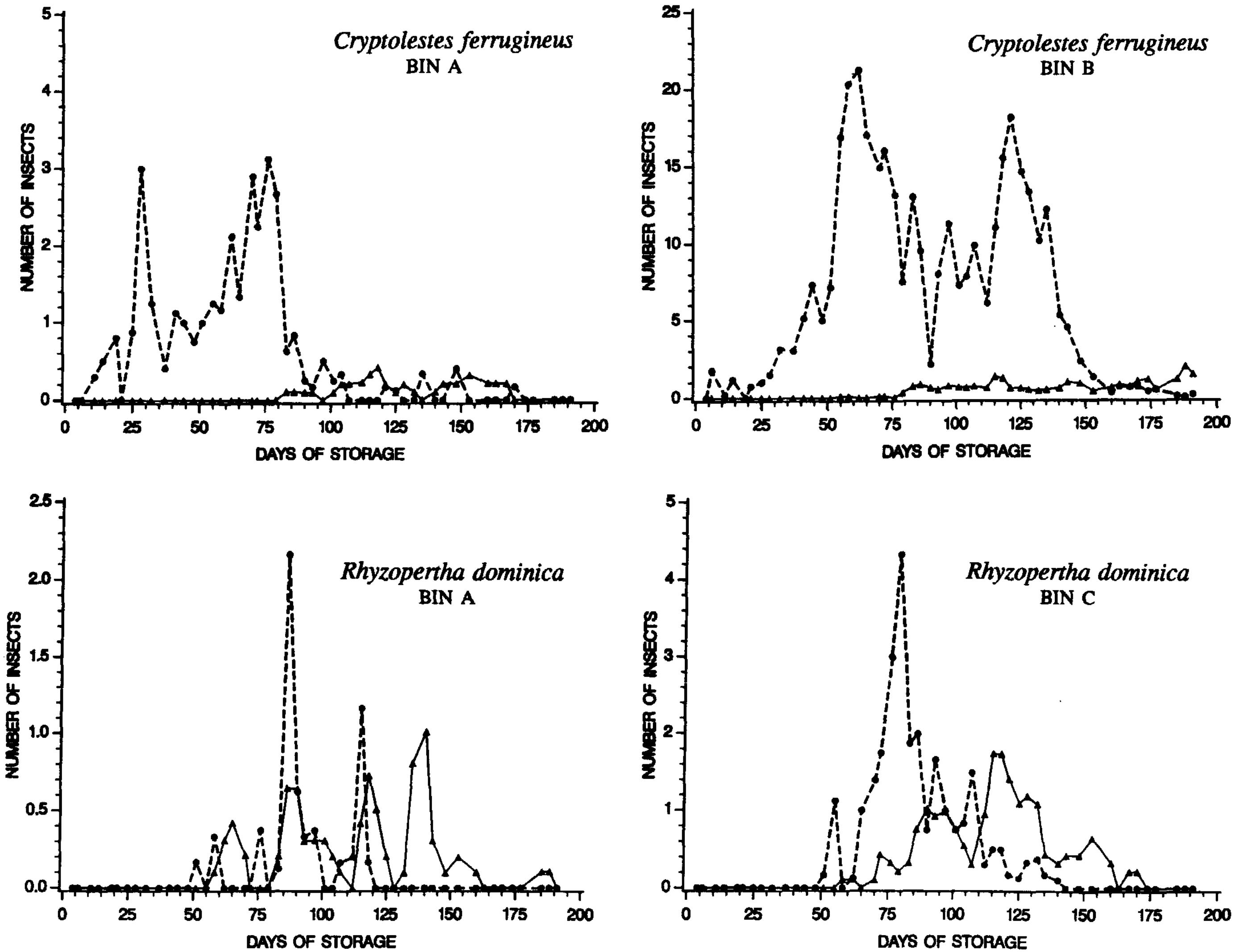

Fig. 2. Changes in insect numbers during the storage period based upon probe trap catch/d (●---●) and number of insects/0.5 kg grain sample (▲—▲). Grain was stored in bins on 9 July 1996.

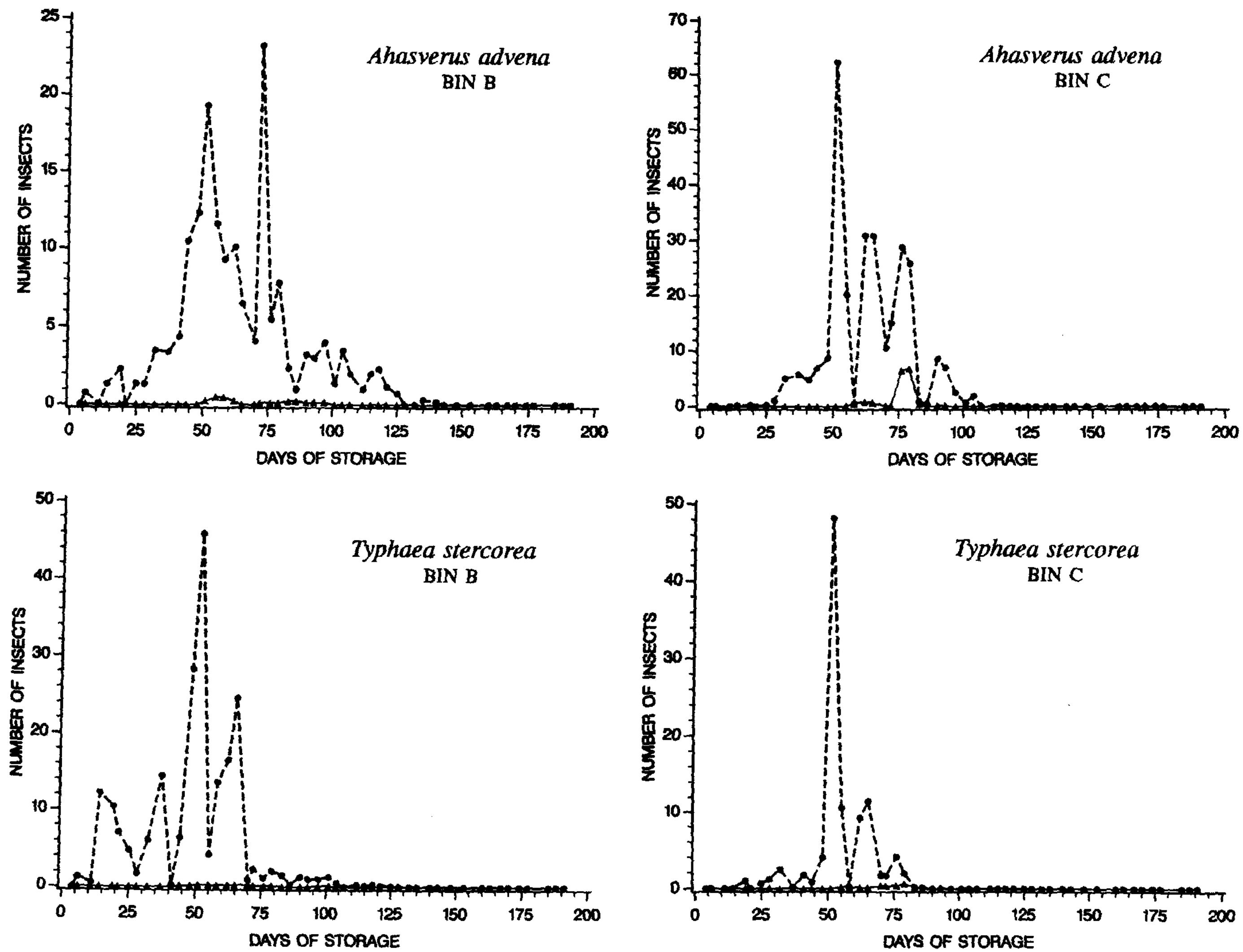

Fig. 3. Changes in insect numbers during the storage period based upon probe trap catch/d (●---●) and number of insects/0.5 kg grain sample (▲—▲). Grain was stored in bins on 9 July 1996.

Table 1. Influence of the depth of probe traps below the surface of stored wheat on the total numbers of each of four insect species captured in each of four bins during a 190-d storage period beginning 9 July 1996

Bin	n[a]	Total numbers of insects caught per day in traps: Top of trap at surface	Top of trap 7.6 cm deep	Number of dates on which differences significant[b]	Ratio[c]	Number of dates with surface trap catch lower[d]
				Cryptolestes ferrugineus		
A	49	1152.0	701.3	3	1.6	9
B	34	91.8	64.2	6	1.4	13
C	18	20.8	23.2	6	0.9	6
D	13	8.4	2.2	3	3.9	3
				Rhyzopertha dominica		
A	16	13.1	12.4	2	1.1	8
B	1	0.3	0	1	—	0
C	23	51.1	51.7	3	1.0	9
D	4	1.8	1.1	1	1.6	2
				Ahasverus advena		
A	35	334.3	97.1	5	3.4	3
B	28	157.9	27.9	6	5.7	2
C	24	557.1	219.2	4	2.5	2
D	17	218.8	47.4	5	4.6	0
				Typhaea stercorea		
A	31	423.0	4.5	7	94.3	0
B	23	168.3	1.2	6	140.3	0
C	20	203.6	9.4	3	21.7	1
D	15	35.5	0.7	4	53.2	0

[a]n is the number of dates on which at least one of two probe traps in each pair caught insects.
[b]Number of dates on which the catches with the tops of probe traps at surface were found to be significantly different ($t > 6$, $P < 0.01$) from catches with the tops of probe traps 7.6 cm below the surface using a t-test.
[c]Ratio of catches with tops of probe traps just below the grain surface to catches with the tops of traps inserted 7.6 cm below the grain surface.
[d]Number of dates on which probe traps with tops at surface caught fewer insects than probe traps with tops 7.6 cm below the grain surface.

traps (r = 0.274 to 0.753; df = 207 to 283; $P < 0.01$). The relationship between the numbers of insects in probe traps and the numbers of insects in grain samples changed over the storage period (Fig. 5). During July, August and September (< 90 d of the storage), average grain temperatures were > 23°C and the numbers of all four insect species in grain samples increased more slowly than the numbers in probe traps. Few *A. advena* or *T. stercorea* were found in traps or grain samples after 90 d of storage. As the average grain temperature decreased from 23 to 14°C during October and early November (90 to 135 d of storage), the number of *C. ferrugineus* and *R. dominica* in probe traps dropped even though the number in grain samples continued to increase. The slopes of equations (Table 2) predicting adult density from trap catch for the first 90 d of storage were significantly different from those for 90 to 135 d of storage for both *C. ferrugineus* (t = 12.48; df = 594; $P < 0.001$) and *R. dominica* (t = 3.72; df = 594; $P < 0.001$). After mid-November (> 135 d of storage), the average grain temperatures were < 14°C and the number of insects in probe traps approached the number of insects in grain samples. The slopes of equations (Table 2) predicting adult density from trap catch for 90 to 135 d of storage were significantly different from those for > 135 d of storage for both *C. ferrugineus* (t = 8.51; df = 418; $P < 0.001$) and *R. dominica* (t = 3.47; df = 418; $P < 0.001$).

The ratios of the number of insects in traps to the number of insects in grain samples tended to decrease over the storage period and differ among species (Table 2). The number of *C. ferrugineus* caught in traps was 107.9 times the number per 0.5 kg grain sample at temperatures above 23°C, 18.7 times within the 23 to 14°C temperature range and 1.8 times below 14°C. Within these same temperature ranges, the number of *R. dominica* caught in traps was 6.4, 1.6 and 0.5 times the number per 0.5 kg grain sample, respectively.

DISCUSSION

For wheat stored in Kansas, the ratio of number of adult insects in traps to number in grain samples has been reported to be lower in November than in September (Reed *et al.*, 1991).

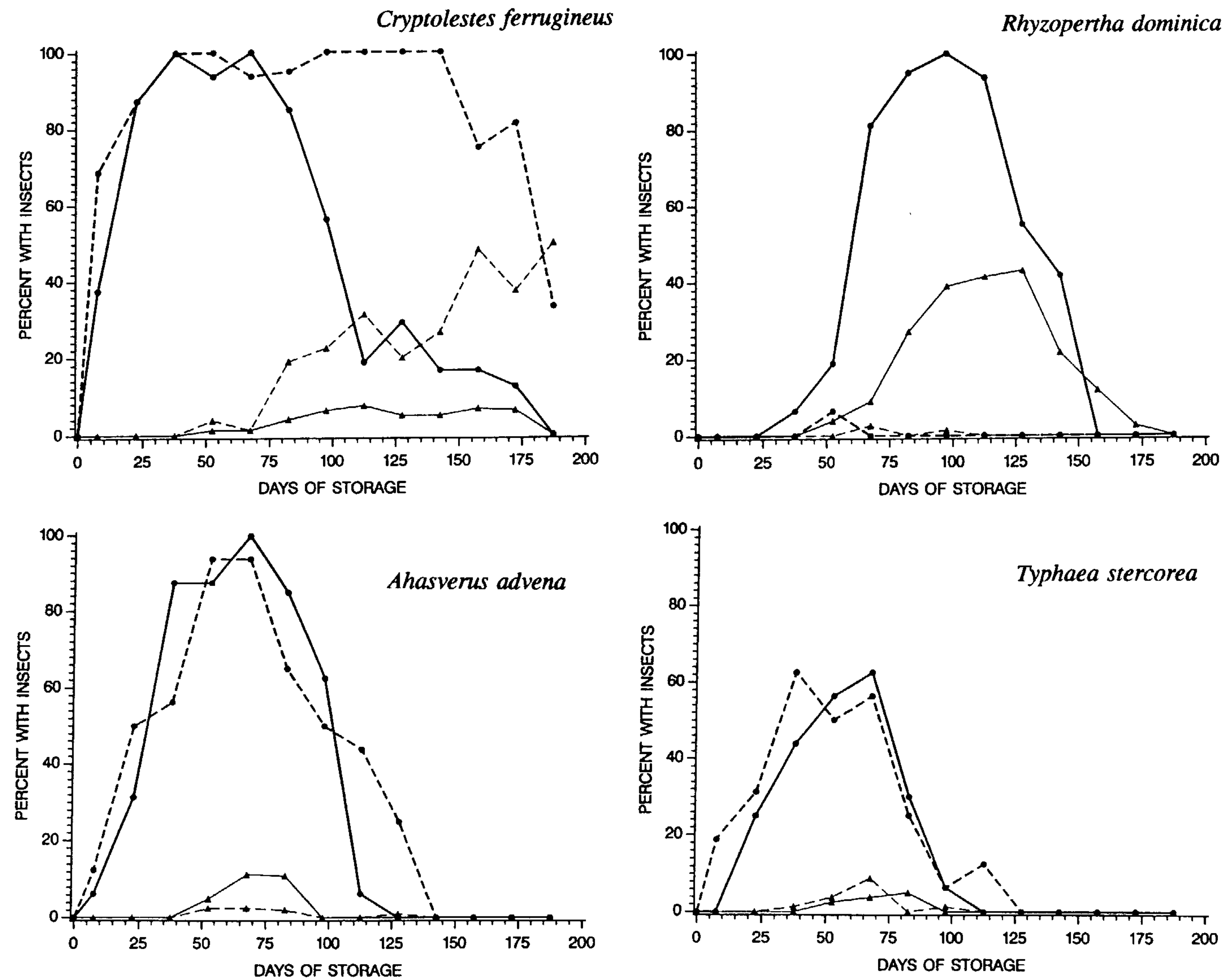

Fig. 4. Percentages of probe traps (●) or grain samples (▲) with insects for bins and species shown in Figs 2 and 3. Percentages were calculated for data collected over a 2-week storage period and were plotted at the midpoint of the time interval. Data are plotted for bins A or C (—) and bin B (- - -).

Table 2. Correlation coefficients and parameters for regression equations predicting number of insects in grain samples from the numbers of insects caught per day in probe traps

Storage period (days)	Grain temperature (°C)	n	β_0 Mean	β_0 SE	β_1 Mean	β_1 SE	r	Trap/grain ratio
			C. ferrugineus					
0–90	>23	384	0.0228	0.0128	0.0093	0.0015	0.303	107.9
90–135	14–23	212	0.0830	0.0280	0.0534	0.0032	0.753	18.7
135–190	<14	208	0.3161	0.0923	0.5485	0.0581	0.549	1.8
			R. dominica					
0–90	>23	384	0.0586	0.0169	0.1563	0.0230	0.329	6.4
90–135	14–23	212	0.4056	0.0729	0.6432	0.1290	0.326	1.6
135–190	<14	208	0.1287	0.0241	1.9519	0.3543	0.358	0.5
			A. advena					
0–90	>23	384	−0.0026	0.0475	0.0296	0.0053	0.274	33.7
			T. stercorea					
0–60	>23	384	0.0402	0.0070	0.0034	0.0010	0.170	296.5

These lower ratios were probably a result of reduced trap catch due to cooler grain temperatures in November than in September. In laboratory studies, Fargo *et al.* (1989) found that probe trap catch was reduced by reducing grain temperature. In the present study, a decrease in this ratio during the storage period was associated with a decrease in grain temperature, which reduced trap catch even though insect populations were growing. The trap to grain sample ratio for *C. ferrugineus* collected in stored wheat by Vela-Coiffier *et al.* (1997) during the summer was roughly two orders of magnitude greater than that of Lippert and Hagstrum (1987) for *C. ferrugineus* collected mostly during the autumn and winter. The current study shows that only a small portion of this 100-fold difference in the ratio was explained by differences between the trap placement in Vela-Coiffier *et al.* (1997) (just below grain surface) and that in Lippert and Hagstrum (1987) (7.6 cm below grain surface). Most of the difference in the ratio of trap catch to number of insects in grain samples between these two studies was probably a result of lower temperatures in the autumn and winter than in the summer.

Trap catch did not estimate adult insect population density consistently throughout the storage period. Interpretation of trap catch is difficult because many factors influence trap catch. A solution to this problem is to convert trap catch to insect density in a known volume of grain (Hagstrum *et al.*, 1990). Trap catch per d (C) can be converted to insect density in grain samples (D) using the equation, $D = \beta_0 + \beta_1 C$, so that the pest population density is estimated consistently throughout the storage period. For a probe trap in grain at >23°C for 7 d that captured 210 *C. ferrugineus*, $\beta_0 = 0.0228$ and $\beta_1 = 0.0093$ (Table 2). Dividing a trap catch of 210 insects by the 7 d of trapping gives a C equal to 30 insects/d. Substituting the values of β_0, β_1, and C into the equation and solving for D, the estimated insect density would be 0.3 insects/0.5 kg grain sample. Other values of β_0 and β_1 from Table 2 would be used for other insect species and temperature ranges. The size of the adjustment that is needed to convert trap catch to insect density in grain samples varied among species and over the storage period. The method developed in the current paper to adjust for the effects of seasonal changes in temperature on probe trap catch will be incorporated into the Stored Grain Advisor expert system (Flinn and Hagstrum, 1990) for making pest management recommendations.

The tendency for a probe trap to catch more insects than are found in a 0.5 kg grain sample is an advantage in detecting low density insect infestations but a disadvantage in estimating insect population density because more insects must be counted. Because the capture rate for probe traps decreased during the storage period, the method for converting trap catch to insect density per 0.5 kg of grain is needed if the same insect density is to be used as an economic threshold for insect control throughout the storage period. Because trap depth influenced species composition, inserting the top of probe traps 7.6 cm below the grain surface was better than just below the grain surface because fewer *T. stercorea* were caught relative to the numbers of the more damaging *R. dominica*. Additional studies may be needed to develop a similar method to adjust for the effect of temperature on trap catch in other types of grain and regions.

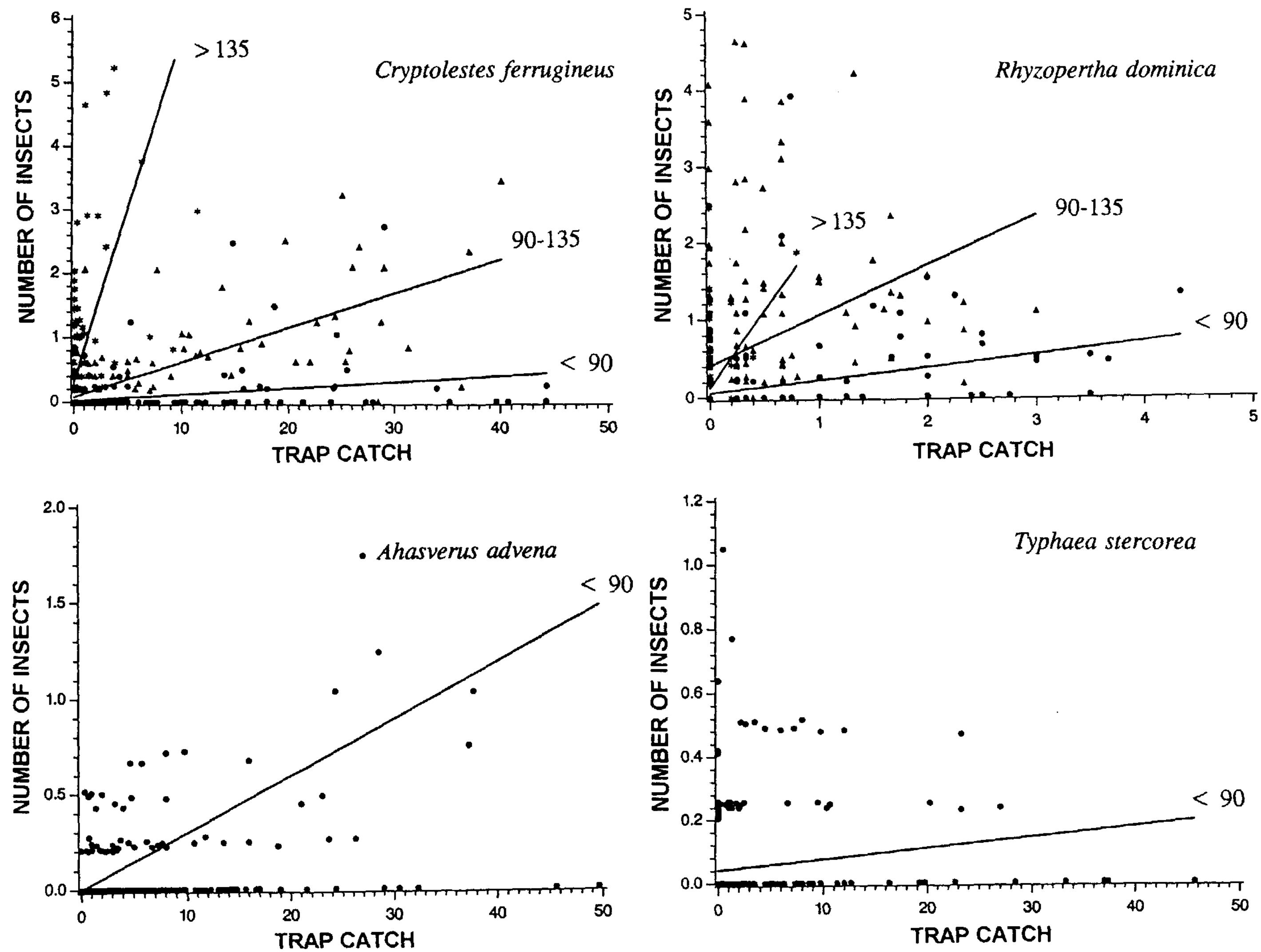

Fig. 5. Number of insects/0.5 kg grain sample predicted from probe trap catch/d using least square regression ( ). Data are fitted separately for July, August and September (< 90 d of storage, > 23°C) (●), for October and early November (90 to 135 d of storage, 23 to 14°C) (▲) and for late November, December and early January (> 135 d of storage, < 14°C) (*). See Table 2 for regression analysis.

Acknowledgements—We are grateful to Brian Barnett for collecting the data, and to Terry Arbogast, Gerrit Cuperus, Richard Mankin, Tom Phillips, Carl Reed and two anonymous reviewers for their helpful suggestions for improving the manuscript.

REFERENCES

Arthur F. H. (1994) Feasibility of using aeration to control insect pests of corn stored in southeast Georgia: simulated field test. *Journal of Economic Entomology* **87**, 1359–1365.

Arthur F. H. (1995) Aeration alone versus chlorpyrifos-methyl treatment followed by aeration for wheat stored in Georgia: simulated field test. *Journal of Economic Entomology* **88**, 1764–1770.

Arthur F. H., Throne J. E., Simonatis R. A. and Zehner J. M. (1990) Evaluation of chlorpyrifos-methyl and chlorpyrifos-methyl plus methoprene as protectants of stored corn: small bin tests. *Journal of Economic Entomology* **83**, 1114–1121.

Barak A. V. and Harein P. K. (1982) Trap detection of stored-grain insects in farm-stored, shelled corn. *Journal of Economic Entomology* **75**, 108–111.

Barak A. V., Burkholder W. E. and Faustini D. L. (1990) Factors affecting the design of traps for stored-product insects. *Journal of the Kansas Entomological Society* **63**, 466–485.

Burkholder W. E. (1984) Stored-product insect behavior and pheromone studies: keys to successful monitoring and trapping. In *Proceedings of the 3rd International Working Conference on Stored-Product Entomology*, pp. 20–33. Kansas State University, Manhattan, KS.

Cuperus G. W., Fargo W. S., Flinn P. W. and Hagstrum D. W. (1990) Variables affecting capture of stored-grain insects in probe traps. *Journal of the Kansas Entomological Society* **63**, 486–489.

Dowdy A. K. and McGaughey W. H. (1994) Seasonal activity of stored-product insects in and around farm-stored wheat. *Journal of Economic Entomology* **87**, 1351–1358.

Fargo W. S., Epperly D., Cuperus G. W., Clary B. C. and Noyes R. (1989) Effects of temperature and duration of trapping on four stored grain insect species. *Journal of Economic Entomology* **82**, 970–973.

Fargo W. S., Cuperus G. W., Bonjour E. L., Burkholder W. E., Clary B. L. and Payton M. E. (1994) Influence of probe trap type and attractants on the capture of four stored-grain Coleoptera. *Journal of Stored Products Research* **30**, 237–241.

Flinn P. W. and Hagstrum D. W. (1990) Stored Grain Advisor: a knowledge-based system for management of insect pests of stored grain. *AI Applications in Natural Resource Management* **4**, 44–52.

Gates M. W. (1995) Population dynamics of lesser grain borer, rusty grain beetle, and *Cephalonomia waterstoni* in commercial elevators. MS Thesis. Oklahoma State University, Stillwater, OK, USA.

Hagstrum D. W., Flinn P. W., Subramanyam Bh., Keever D. W. and Cuperus G. W. (1990) Interpretation of trap catch for detection and estimation of stored-product insect populations. *Journal of the Kansas Entomological Society* **63**, 500–505.

Hagstrum D. W., Flinn P. W. and Fargo W. S. (1995) How to sample grain for insects. In *Stored Product Management*, pp. 65–69. Oklahoma State University Cooperative Extension Service Circular E-912, Stillwater, OK, USA.

Hillmann R. C. (1991) Performance and grower acceptance of probe-pitfall traps used to monitor Coleoptera that infest farm-stored corn in northeastern North Carolina. In *Proceedings of the 5th International Working Conference on Stored-Product Protection*, pp. 1361–1367. Bordeaux, France.

Lippert G. E. and Hagstrum D. W. (1987) Detection or estimation of insect populations in bulk-stored wheat with probe traps. *Journal of Economic Entomology* **80**, 601–604.

Loschiavo S. R. (1974) Laboratory studies of a device to detect insects in grain, and of the distribution of adults of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), in wheat-filled containers. *The Canadian Entomologist* **106**, 1309–1318.

Loschiavo S. R. (1975) Field tests of devices to detect insects in different kinds of grain storages. *The Canadian Entomologist* **107**, 385–389.

Loschiavo S. R. (1985) Post-harvest grain temperature, moisture, and insect infestation in steel granaries in Manitoba. *The Canadian Entomologist* **117**, 7–14.

Loschiavo S. R. and Atkinson J. M. (1967) A trap for the detection and recovery of insects in stored grain. *The Canadian Entomologist* **99**, 1160–1163.

Loschiavo S. R. and Atkinson J. M. (1973) An improved trap to detect beetles (Coleoptera) in stored grain. *The Canadian Entomologist* **105**, 437–440.

Loschiavo S. R. and Smith L. B. (1986) Population fluctuations of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), monitored with insect traps in wheat stored in a steel granary. *The Canadian Entomologist* **118**, 641–647.

Loschiavo S. R., Wong J., White N. D. G., Pierce H. D. Jr, Borden J. H. and Oehlschlager A. C. (1986) Field evaluation of a pheromone to detect adult rusty grain beetles, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), in stored grain. *The Canadian Entomologist* **118**, 1–8.

Madrid F. J., White N. D. G. and Loschiavo S. R. (1990) Insects in stored cereals, and their association with farming practices in southern Manitoba. *The Canadian Entomologist* **122**, 515–523.

Parajulee M. N. and Phillips T. W. (1995) Seasonal abundance and spatial patterns of the predator *Lyctocoris campestris* in stored corn. *Entomologia Experimentalis et Applicata* **75**, 33–42.

Pereira P. R. V. S., Lazzari F. A., Lazzari S. M. N. and Almeida A. A. (1994) Comparison between two methods of insect sampling in stored wheat. In *Proceedings of the 6th International Working Conference on Stored-Product Protection*, pp. 435–438. Canberra, Australia.

Plarre R. (1996) Three-dimensional distribution of *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) in wheat influenced by the synthetic aggregation pheromone. *Journal of Stored Products Research* **32,** 275–283.

Reed C. R., Wright V. F., Mize T. W., Pedersen J. R. and Brockschmidt Evans J. (1991) Pitfall traps and grain samples as indicators of insects in farm-stored wheat. *Journal of Economic Entomology* **84,** 1381–1387.

SAS Institute (1990) *SAS/STAT User's Guide*, version 6, 4th edn. SAS Institute, Cary, NC, USA.

Shuman D., Coffelt J. A. and Weaver D. K. (1996) A computer-based electronic fall-through probe insect counter for monitoring infestations in stored products. *Transactions of the American Society of Agricultural Engineers* **39,** 1773–1780.

Subramanyam Bh. and Harein P. K. (1989) Insects infesting barley stored on farms in Minnesota. *Journal of Economic Entomology* **82,** 1817–1824.

Subramanyam Bh., Harein P. K. and Cutkomp L. K. (1989) Field tests with probe traps for sampling adult insects infesting farm-stored grain. *Journal of Agricultural Entomology* **6,** 9–21.

Subramanyam Bh., Hagstrum D. W. and Schenk T. C. (1993) Sampling adult beetles (Coleoptera) associated with stored grain: comparing detection and mean trap catch efficiency of two types of probe traps. *Environmental Entomology* **22,** 33–42.

Subramanyam Bh., Swanson C. L., Madamanchi N. and Norwood S. (1994) Effectiveness of Insecto®, a new diatomaceous earth formulation, in suppressing several stored-grain insect species. In *Proceedings of the 6th International Working Conference on Stored-Product Protection*, pp. 650–659. Canberra, Australia.

Vela-Coiffier E. L., Fargo W. S., Bonjour E. L., Cuperus G. W. and Warde W. D. (1997) Immigration of insects into on-farm stored wheat and relationships among trapping methods. *Journal of Stored Products Research* **33,** 157–166.

Weinzierl R. and Porter P. (1988) Insects in stored grain: Illinois survey findings and management recommendations. In *Proceedings Illinois Agricultural Pesticides Conference*, pp. 176–187. Champaign, IL.

White N. D. G. and Loschiavo S. R. (1986) Effects of insect density, trap depth, and attractants on the capture of *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in stored wheat. *Journal of Economic Entomology* **79,** 1111–1117.

White N. D. G. and Loschiavo S. R. (1988) Effects of localized regions of high moisture grain on efficiency of insect traps capturing adult *Tribolium castaneum* and *Cryptolestes ferrugineus* in stored wheat. *Tribolium Information Bulletin* **28,** 97–100.

White N. D. G., Arbogast R. T., Fields P. G., Hillmann R. C., Loschiavo S. R., Subramanyam Bh., Throne J. E. and Wright V. F. (1990) The development and use of pitfall and probe traps for capturing insects in stored grain. *Journal of the Kansas Entomological Society* **63,** 506–525.

Wright V. F. and Mills R. B. (1984) Estimation of stored-product insect populations in small bins using two sampling techniques. In *Proceedings of the 3rd International Working Conference on Stored-Product Entomology*, pp. 672–679. Kansas State University, Manhattan, KS, USA.